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The Behaviour of the Norway Lobster, *Nephrops norvegicus* (L.), During Trawling

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The Behaviour of the Norway Lobster, *Nephrops norvegicus* (L.), During Trawling

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Introduction

The Norway lobster, *Nephrops norvegicus* (L.) (Plate I), commonly called the "prawn", is widely distributed around Scotland and supports an important inshore fishery (Howard, 1982). *Nephrops* are caught by baited creels and specially designed light demersal trawls on grounds where the sea bed consists of fine cohesive mud, in which they excavate burrows (Barnes and Bagenal, 1951; Dybern and Hoiseter, 1965; Chapman and Rice, 1971; Rice and Chapman, 1971; Atkinson, 1974). It is often assumed that size selection during trawling for *Nephrops* is mainly controlled by the cod-end mesh size, but it has been shown that *Nephrops* also escape from other parts of some trawls (Cole and Simpson, 1965; Pope and Thomas, 1965; Hillis, 1979, 1983; Hillis and Earley, 1982).

Plate I. The Norway lobster, *Nephrops norvegicus*. The animal in the foreground is out on the muddy surface of the sea bed; the one in the background is just emerging from its burrow.

Nephrops selection during trawling is influenced by a combination of the behaviour of the animal and the design and rigging of the net. The behaviour and ecology of these animals is fairly well documented (Cole, 1965, 1967; Chapman, Priestley and Robertson, 1972; Farmer, 1974; Chapman, Johnstone and Urquhart, 1974; Chapman, Johnstone and Rice, 1975), but little information is available on the behavioural responses of *Nephrops* when approached by a moving trawl. Main and Sangster, (1982a), using

direct observation techniques in daylight, reported that *Nephrops* did not swim higher than 1 m from the sea bed when disturbed by the groundline of a Boris 520 fish/prawn trawl and passed back into the net only through the width of the bosom groundline. Furthermore, recent unpublished observations by the authors showed marketable sized *Nephrops* (carapace length (CL) = 30–35 mm) passing through the belly panels and underside cod-end meshes (70 mm) of a dual purpose fish/prawn trawl during daylight commercial fishing on grounds off the West Coast of Scotland. In view of these observations and the need to establish these findings, further experiments were planned. This paper describes experiments to investigate the behaviour and selection of *Nephrops* during trawling. The work is in two parts, direct observations on the reactions of *Nephrops* to the trawling gear and studies of the escape areas of the trawl using small mesh covers and direct observation.

Materials and Methods

The experiments were conducted in daylight during spring and summer of 1981 and 1982 on commercial *Nephrops* fishing grounds (depth 35–130 m) around the Small Isles near Mallaig, Scotland (57°01'N 04°42'W), using the local prawn trawler "Orcades" OB 232(320 hp, 22 m). In addition to the trawl gear, this vessel towed the diver-operated towed underwater vehicle TUV II (Main and Sangster, 1978a, 1983a, 1984a) for observations in shallow water (depth 35–40 m) and the Remote Controlled Towed Underwater Vehicle RCTV (Priestley, in preparation; Main and Sangster, 1982b) for observations in deeper water (50–90 m). Both vehicles carried a low-light television camera and could be steered into any position near the fishing gear. Still photographs were obtained using a Nikonos III 35 mm underwater camera fitted with either a 15 mm or a 28 mm lens. Ilford HP5 and Agfapan Vario – XL negative films rated at 800 ASA were used throughout the experiments, usually with natural illumination but occasionally with electronic flash.

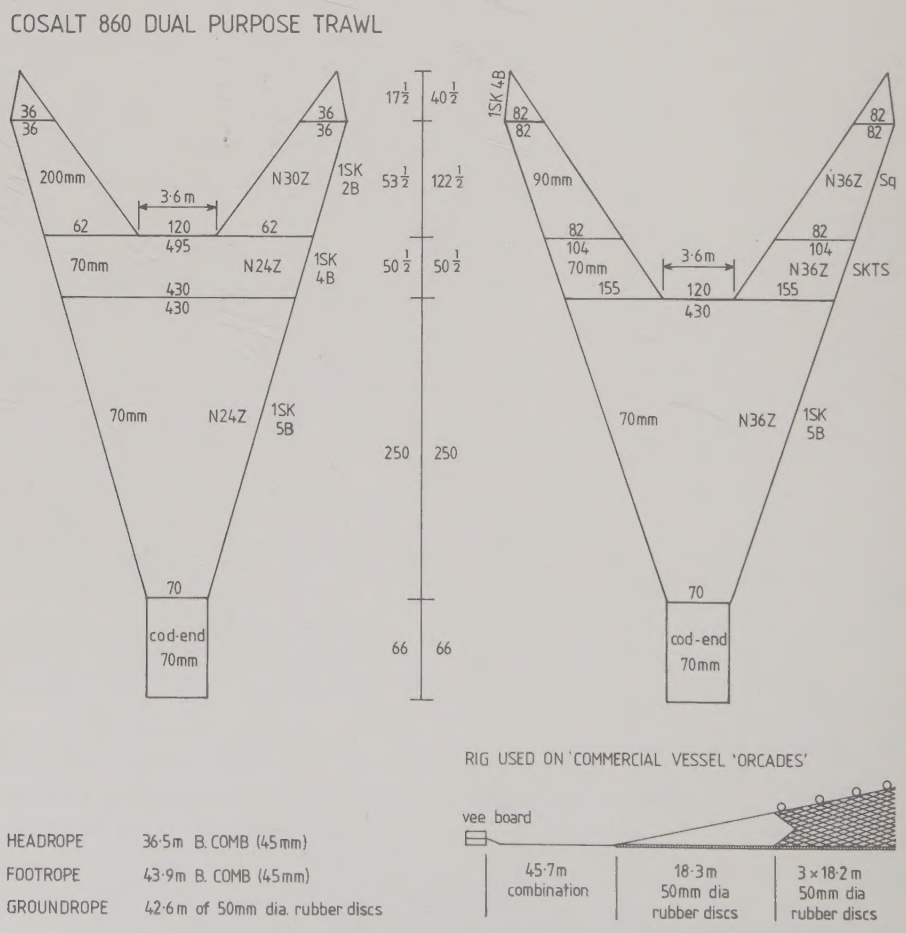

Figure 1. Net diagram and rigging specification of the Cosalt 860 Dual Purpose fish/prawn trawl.

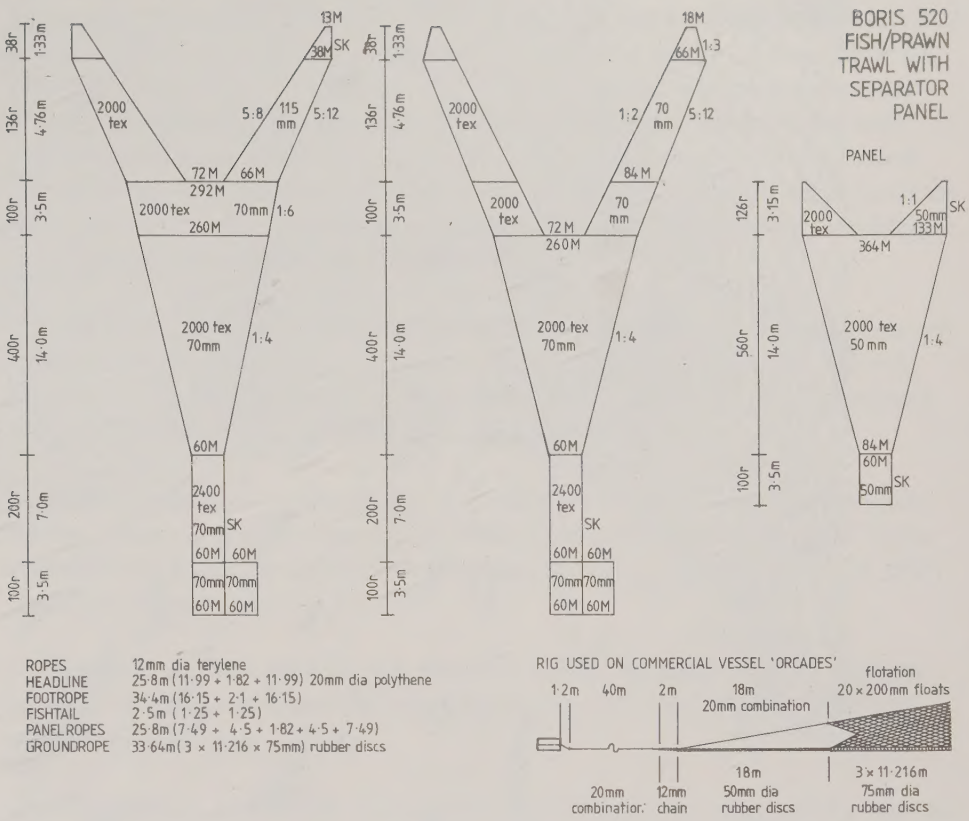

Figure 2. Net diagram and rigging specification of the Boris 520 fish/prawn trawl with the 50 mm stretched mesh separator panel.

Towing speed was monitored using two propeller-type speed logs, one towed at the surface by the "Orcades" and one on the TUV II. The duration of the trawl tows varied from 2 to 5 hours. The nets used were a Cosalt 860 dual purpose two-panel trawl (belonging to "Orcades"), rigged specifically for prawn fishing and a Boris 520 fish/prawn trawl (Figs 1 and 2). The Boris net was rigged with a second fishing line on a horizontal separator panel (50 mm stretched mesh) which divided the net into two horizontal compartments (Fig. 3) terminating in separate cod-ends (Main and Sangster, 1982a, b; 1984 a, b). The height of the separator panel was set at 75 cm above the groundline. The method of controlling the height of internal panels of netting in trawls was described by Main and Sangster (1982a). The trawl boards were steel, rectangular Vee-type (2.0 x 1.2 m). The dimensions of the two-level Boris trawl were measured while fishing in shallow water by the divers in TUV II. The various techniques used for measuring fishing gears in action using TUV II and its instrumentation were described by Main and Sangster (1981a, b; 1983a, b). The Cosalt 860 trawl was measured while fishing in deeper water (90-130 m) using remote instruments attached to the trawl, most of which are described by Urquhart (1981). These self-recording instruments provided a continuous record of the gear shape during each experiment (eg otterboard spread, wing-end spread and headline height). The contents of the cod-end(s) and covers were kept separate, measured and counted on completion of each haul. Cod-end stretched mesh sizes were measured using ICES gauge (Parrish and Pope, 1964), the tension calibration being set at 1.82 kg.

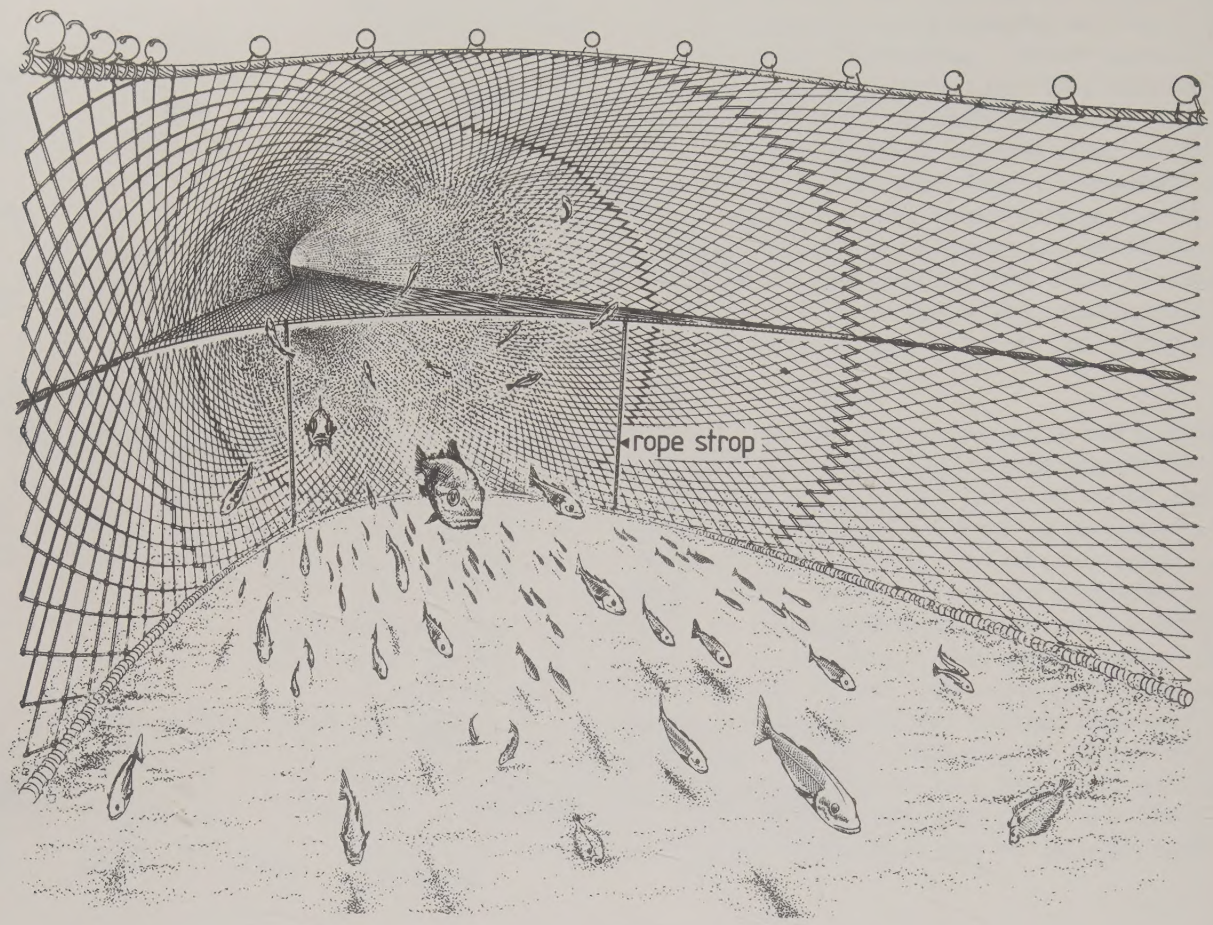

Figure 3. Illustration of the mouth opening of the two-level trawl. The vertical lines represent the position of the rope strops, the length of which controls the height of the separator panel above the ground line.

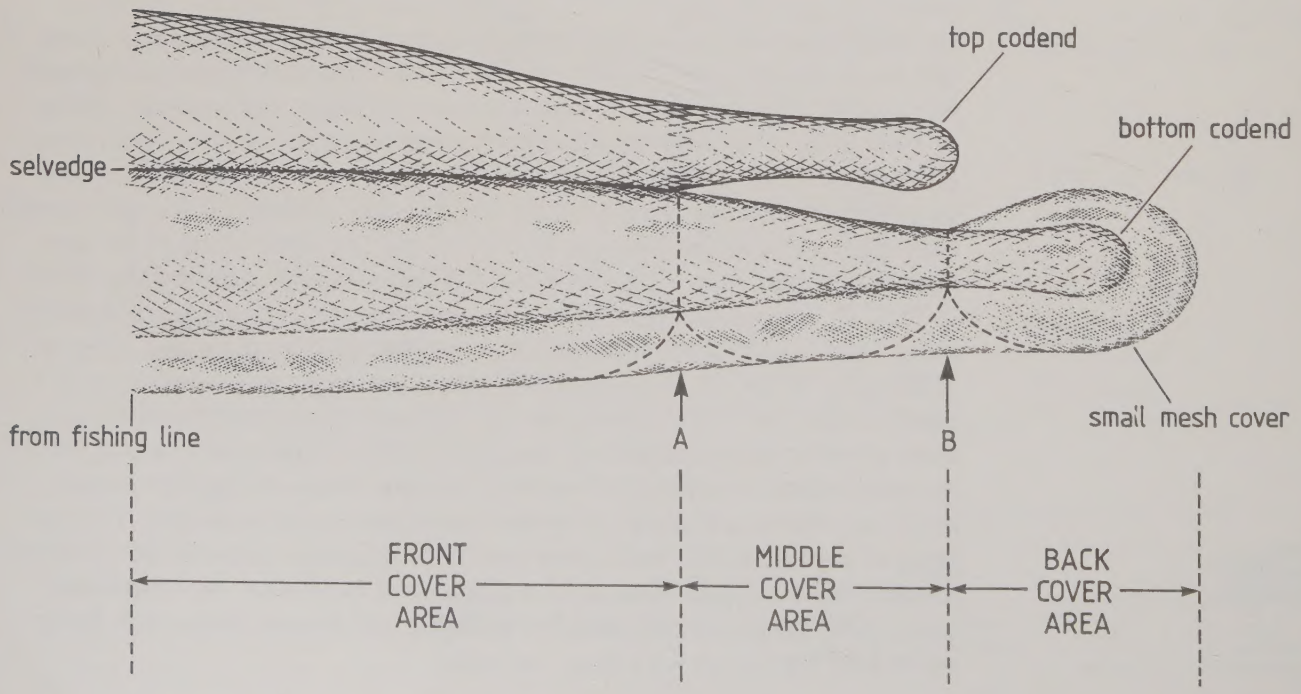

Figure 4. Boris 520 two-level trawl showing the area covered by the 40 mm mesh cover. By lacing up the small mesh to the main net at points A and B the contents of the cover were separated into three areas, front, middle and back.

An experimental cover (40 mm, 1200 TEX stretched mesh) was fitted to the Boris net during the *Nephrops* selectivity and escape experiments. This cover was designed to retain all *Nephrops* passing out of the lower half of the two-level trawl. The cover was rigged from selvedge to selvedge and as far forward as the bosom groundline, back to and including the whole cod-end (Fig. 4). The cover was divided to identify *Nephrops* escaping from the three areas shown in Figure 4. In some experiments the standard bottom cod-end (70 mm) was replaced by an intermediate mesh (80 mm) and a large mesh (90 mm) cod-end. The top cod-end remained unchanged at (70 mm) because previous results with a two-level trawl had shown that *Nephrops* were caught only in the lower cod-end (Main and Sangster, 1982a).

The immature *Nephrops* Order (UK) 1979, prohibits the landing and sale of *Nephrops norvegicus* with a carapace length of less than 25 mm. For the purpose of our experiments <25 mm CL was considered under-sized and the catches in the different cod-ends were split on this basis.

Nineteen hauls were carried out to compare the catches from five compartments, (ie top and bottom cod-end, front, middle and lower covers). Some variations of the cover compartments were made by removal of one or both "laced-up" points (A, B in Fig. 4).

Fluorescein dye was used by the divers to reveal the water flow in the area between the net and this small mesh cover using the techniques described in Main and Sangster (1978b).

Results

Measurement of the Fishing Gears

The dimensions and towing speeds of both fishing gears, obtained by remote instruments and diving techniques are given in Table I.

Table I Dimensions of Cosalt 860 trawl and Boris 520 two-level trawl

	Cosalt 860 Trawl	Boris 520 two-level Trawl
Trawl board spread	38.6m	30m
Wing end spread	13.5m	10.3m
Sweep and bridle length	64m	61.2m
Bridle angle	11.5°	9.5°
Headline height	2.5m	3.05m
*Towing speed at 650 rpm	1.2 to 1.4m s^{-1}	1.2 to 1.4m s^{-1}
Warp between ship and otter boards	300m	150m
Depth of water	90–130m	35–40m

*This is the normal towing speed used by the "Orcades" when fishing for *Nephrops*.

The two nets used in these experiments are both dual purpose trawls, *ie* used for both *Nephrops* and white fish trawling. The two-level Boris 520 net is a smaller net than the Cosalt 860, having 520 (70 mm) meshes compared with 860 (70 mm) meshes around the net mouth opening (see Figs 1 and 2). However, in Table I it can be seen that, owing to the rigging of headline floats, the headline height and wing-end spread measurements are not very different. Furthermore, when trawling for fish (*eg* haddock and whiting) a high headline (3–4 m) is more important than when fishing for *Nephrops*, where only 1–2 m of height would be more than sufficient. An 860 size two-level trawl would have given the ideal comparison but in order to link

with earlier results of fish and *Nephrops* separation the same modified Boris 520 two-level net was chosen.

Direct Observations of *Nephrops* Behaviour

The *Nephrops* in the area of Mallaig are traditionally fished during daylight hours and it was found possible using natural daylight to observe and record the behaviour of both fish and *Nephrops* down to a limit of 90 m using the low-light TV camera. Underwater visibility ranged from 2 to 5 m during the work.

Observations with the RCTV

Television recordings were made of 9 hauls using the Cosalt 860 dual purpose trawl. These continuous recordings using natural light (up to 3 hours duration per haul) included observations of swept areas near to and between the otterboards, along and between port and starboard sweep wires and wing-ends, and in front of the bosom groundline. The remote camera allows passing observations with a fixed view so that many repeated observations at different point in the gear allows us to build up a general picture of the reactions of the *Nephrops* passing back into the gear.

Although many burrows were present, no *Nephrops* were seen during observations back and forth between the port and starboard otterboards over a period of 5.5 hours. Although the density and spacing of burrows varies considerably from area to area, an estimated figure of one *Nephrops* per m^2 would be expected in this fishery. Note that this figure would include undersized and juvenile *Nephrops, ie* one per m^2 is not the density of commercial sized *Nephrops* (C.J. Chapman personal communication). In the area between the otterboard to the wing-end, 25 *Nephrops* were observed during one 20 minute period whilst manoeuvering the RCTV. These animals were seen in or near the entrance of a burrow about half way between the board and the wing-end 2–3 m ahead of and inside the sweep wire. Twenty-one of these *Nephrops* were seen to be touched by the sweep wire and to swim a few centimetres above the sea-bed, allowing the wire to pass underneath them (Plate II). Observations on the other four animals were incomplete and no conclusions were drawn from them.

Plate II. A *Nephrops* **about to be overtaken by the trawl bridle.**

During another 8 minute observation period just ahead of the wing-end, 14 *Nephrops* were seen to rise from the sea-bed and pass over the bridle out of the net path and escape. A total of 42 individual observations were made at this same position of *Nephrops* being overtaken by the trawl bridle. No *Nephrops* were herded inwards by the sweeps or bridles during 4 hours of observation. *Nephrops* were seen on the surface of the sea-bed in the area just ahead of the groundrope between the wings of the net. During one 6 minute observation period, 27 individuals were seen to swim off the sea-bed over the groundrope and to collide with the lower wing meshes before rolling and tumbling into the net mouth. Three hours were spent observing *Nephrops* in an area just ahead of the bosom groundline. Of 46 *Nephrops* seen, none swam higher than about 60–70 cm from the sea-bed when disturbed and all passed back over the footrope. The footrope was often partially obscured by a low cloud of mud streaming off the top of the rubber disc groundline. Those *Nephrops* that could be followed remained close to the belly netting as they rolled and tumbled along the funnel towards the cod-end. None were seen swimming in the clear water approximately 1 m above this belly panel.

Divers observations from TUV II

During the course of each dive, both occupants of the underwater vehicle had the specific task of looking for *Nephrops,* either at the entrances of burrows or out on the surface of the mud, and describing their individual reactions to the components of the advancing fishing gear. Fifty-six dives were carried out (duration 10–15 minutes) at 35–40 m, providing daylight observations and some television recordings of *Nephrops* and fish reactions to the modified two-level Boris 520 fish/prawn trawl.

These observations, although shorter in time than those from the remote television vehicle, have the advantage that the human eye could follow individual *Nephrops* in detail, allowing the observer who is pointing the TV camera to record the complete sequence of behaviour.

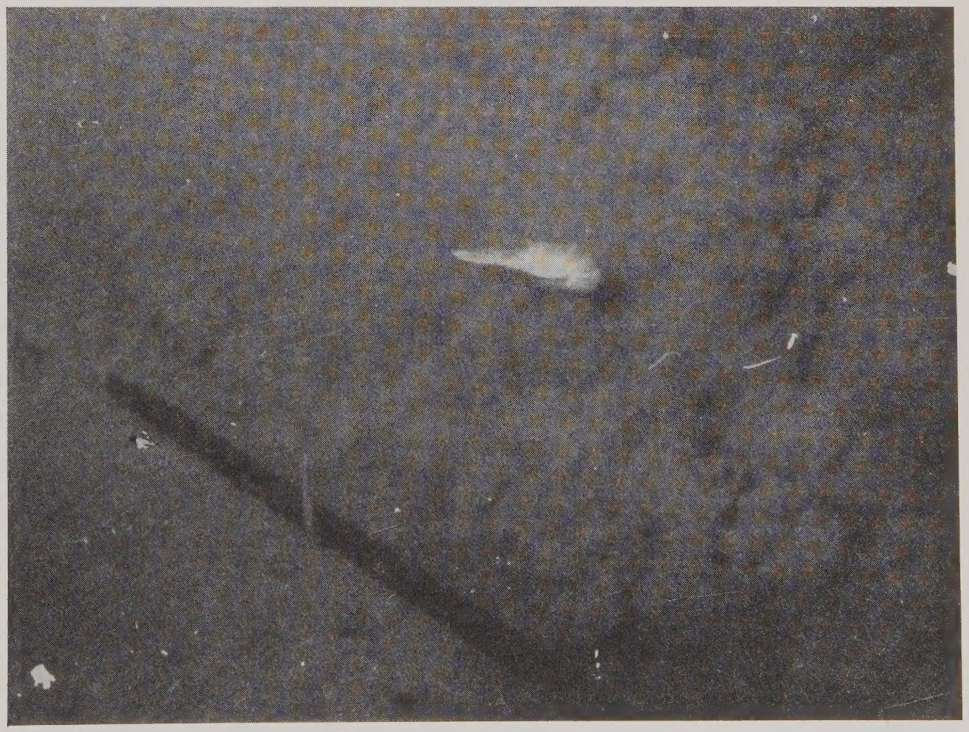

Plate III. The bridle has passed under the *Nephrops*. The animal is now outside the path of the approaching net.

Plate IV. A *Nephrops* out on the mud surface. In this position its chances of avoiding capture in an advancing net are low.

At the otterboards, only one *Nephrops* was seen out on the mud surface during 120 minutes of searching (although 17 *Nephrops,* sometimes with only claws visible, were seen at burrow entrances). This individual responded initially by backing slowly away with its claws raised, but when the otterboard was approximately 1 m distant it made one rapid flexing of the tail and moved 2 m away from the path of the board. Thirty-seven *Nephrops* were seen in a region 2 m inside the sweep wires and 5 m ahead of the wing-end during a 15 minutes observation period. All were overtaken by the wire and passed out of the net path (Plate III); no herding was apparent. *Nephrops* were observed on the surface of the sea-bed just ahead of, and at the wing-ends. During an 8 minutes period seven individuals were seen to swim up approximately 50 cm and over the groundline, collide with one of the wings then tumble back into the net. Approximately 300 minutes were spent watching the behaviour of *Nephrops* near the centre of the groundline . Those *Nepthrops* seen out of their burrows (Plate IV) (55 individuals during one 14 minute dive) were all caught; 22 swam into the net, 32 were hit by the approaching groundline before entering the net and three *Nephrops* reacted by swimming ahead of the trawl before capture. Of these last three, two were quickly lost from view but one swam for 9 seconds using 27 flicks of its tail to maintain a position ahead of the groundline at a towing speed of 1.3 m s^{-1} before passing over the footrope into the net. All *Nephrops* seen (33 during one 11 minute dive) in the entrance to their burrows (Plate V and VI) escaped capture by quickly withdrawing deeper into their burrows as the ground-line approached to within 0.5 to 2m. All the *Nephrops* caught swam up sharply about 50—60 cm over the rapidly advancing bosom groundline and rolled and tumbled close to the belly panel as the net passed under them and so back to the cod-end. No animals were seen to escape down through the belly panels, but it was not uncommon to see *Nephrops* tails and claws sticking out through the meshes in this area.

Plate V. A *Nephrops* in this position is well protected from the advancing trawl.

Plate VI. Even in this position (half out of the burrow entrance) the *Nephrops* can withdraw quickly downwards to avoid the trawl.

During one 10 minute dive at the cod-end 6 *Nephrops* (below and above marketable size) were observed escaping from the cod-end (70 mm). Typically, these *Nephrops* were hooked on to meshes on the underside of the cod-end and appeared to escape by being forced through the mesh by the flow of water from within the cod-end.

Comparative *Nephrops* Trawling *Catches with the Cosalt 860 dual purpose trawl*

The Cosalt 860 trawl was considered to be representative of the gear used by the fleet working in the Mallaig area. Fifty meshes selected at random from the 70 mm cod-end were measured using the ICES gauge, giving a mean stretched mesh size of 69 mm (range 65–73 mm). The total catch of *Nephrops* after each haul was found to be similar to the catches of three

Table II Catches from 16 daylight hauls of 2–4 hours duration using the two-level Boris 520 fish/prawn trawl. Depth 90–125 m

Species	Top level		Bottom level		Total catch of each species (numbers)
	% of total catch	Size range (cm)	% of total catch	Size range (cm)	
Haddock	91.4	24–25	8.6	15–39	796
Whiting	81.8	18–52	18.2	15–34	678
Herring	94.3	16–26	5.7	14–17	123
Nephrops	0	-	100	17–51*	75,179
Cod	0	-	100	19–79	83
Skates	0	-	100	34–59	53
Angler	0	-	100	26–45	147
Flatfish	0	-	100	9–40	2,102

*Carpace length in mm

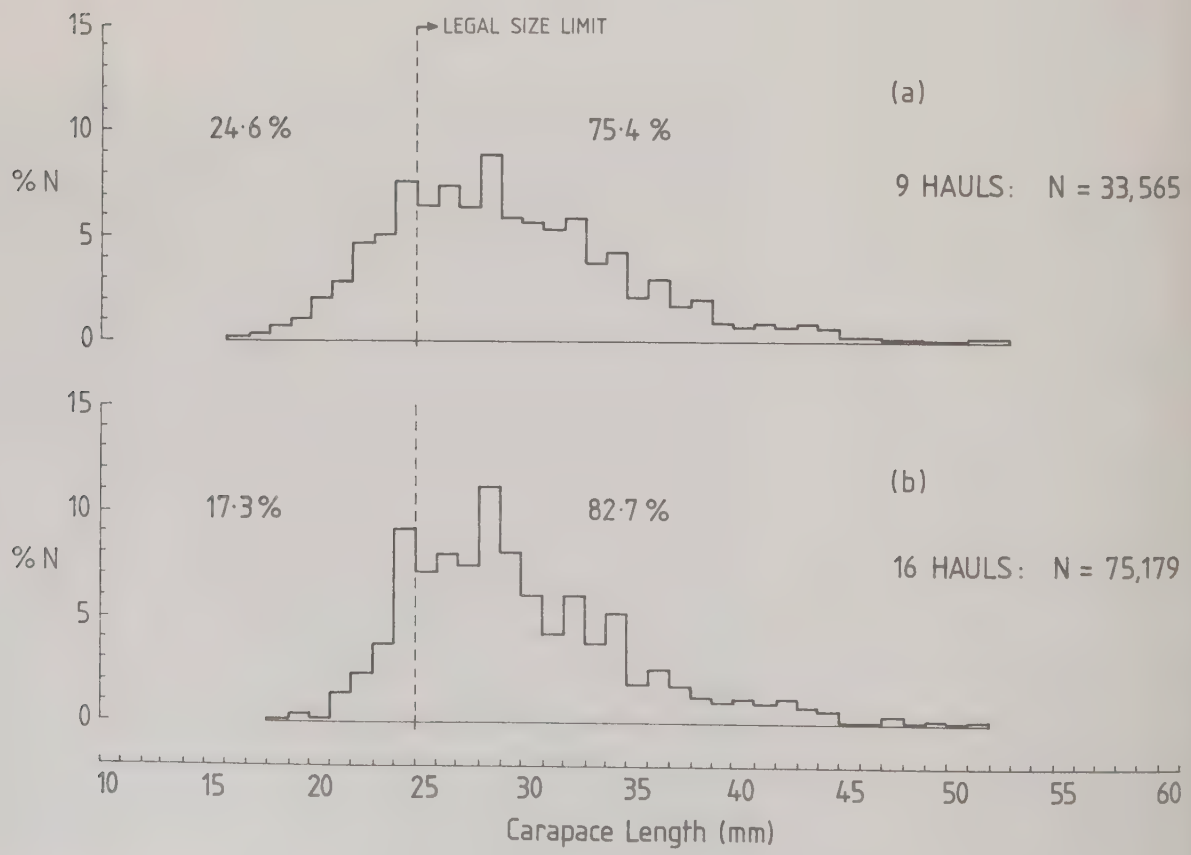

Fig. 5 Comparison of the length frequency distribution of the *Nephrops* catches in the 70 mm cod-end of (a) commercial Cosalt 860 trawl (nine hauls of 2–4 hours duration, depth 50–140 m) and (b) modified two-level Boris 520 trawl (bottom cod-end, 16 hauls of 2–4 hours duration, depth 90–125 m).

other fishing vessels on these grounds using similar nets and cod-ends. The size composition of *Nephrops* in the catches is shown in Figure 5a. The proportion of marketable sized and undersized *Nephrops* were 75.4 and 24.6% respectively. These data were obtained for the Cosalt 860 trawl, so that comparisons could be made with the experimental two-level trawl fished on the same grounds on subsequent days. Figure 5a is a length estimation of the commercial *Nephrops* catches (*not* landings) in the Small Isles fishing grounds. It does not represent the length range of *Nephrops* landings as the crews select out the under-sized specimens to comply with the regulations on landings.

Catches with the modified two-level Boris 520 fish/prawn trawl

Sixteen daylight hauls were carried out with the modified two-level Boris trawl. The distribution of fish species and *Nephrops* caught are shown in Table II. This trawl successfully separated the majority of haddock (*Melanogrammus aeglefinus* (L.)), whiting (*Merlangius merlangus* (L.)) and herring (*Clupea harengus* L.) into the top cod-end, whereas *Nephrops,* cod (*Gadus morhua* (L.)), skates (*Rajidae*), angler (*Lophius piscatorius* L.), plaice (*Pleuronectes platessa* (L.)). common dab (*Limanda limanda* (L.)) and lemon sole (*Microstomus kitt* (Walbaum)) were recovered only from the bottom cod-end. These results confirm earlier experiments using the same two-level separator trawl (Main and Sangster, 1982a, b and 1984b).

The catch rate of fish and *Nephrops* from each hauls was similar to that of Cosalt 860 trawl fished by "Orcades" and three commercial prawn boats in the area. It appeared, therefore, that the modified two-level net fished equally well as the commercial nets in use on the grounds. The length distribution of the *Nephrops* in the catch of the bottom cod-end is summarised in Figure 5b. The proportions of marketable sized and under-sized *Nephrops* were 82.7 and 17.3% respectively.

The average catch rate of the Cosalt 860 trawl was 1,680 *Nephrops* per hour compared with 1,570 *Nephrops* per hour for the Boris 520 net. On the whole, both nets showed very similar catches using the same 70 mm mesh cod-end (Fig. 5).

Table III Stretched mesh sizes in cod-ends and cover

Net area	Nominal mesh size (mm)	Measured mesh size mean (mm)	range (mm)
Top cod-end	70	68	66–71
Bottom cod-end	70	72	68–74
Bottom cod-end	80	82	75–86
Bottom cod-end	90	92	90–97
Small mesh covers	40	40	38–41
Net belly panel	70	72	69–74

Table IV *Nephrops* catches using the standard bottom cod-end (70 mm) and small mesh covers of Boris 520 trawl. Data from nine daytime hauls. Depth 56–110 m, duration 2 to 3 hours. *Nephrops* of all sizes are included. The percentage of the total catch is given for *Nephrops* in each area of the trawl and also the aggregate percentage loss from the net (*ie* the sum total of *Nephrops* recovered from all divisions of the cover)

Haul	% retained in bottom cod-end	% lost to cover division			% total loss into covers from covered net	Cod-end + all covers Total catch in numbers (N)
		Front	Middle	Back		
1	50.3			49.7	49.7	5,894
2	59.1			40.9	40.9	10.608
3	76.9	1.7		21.4	23.1	9,963
4	78.0	4.6		17.4	22.0	12,441
5	54.6	40.6		4.8	45.4	22,121
6	76.3	8.0	14.0	1.7	23.7	14,152
7	92.8	1.2	2.8	3.2	7.2	1,909
8	74.1	0	22.3	3.6	27.9	4,524
9	85.4	0	3.4	11.2	14.6	1,180
average	71.8				28.2	total 82,792

The Escape of *Nephrops* During Trawling

Measurements and catches with the 70 mm cod-end

Fifty meshes selected at random from each cod-end, the net belly panel and each of the cover areas were measured using the ICES gauge (Table III). Direct observations by divers of dye released from hand-held dye containers showed no measurable change in the water flow when comparing both the uncovered and covered net. During towing the small mesh cover was seen to billow away from the main net forming spaces of about 20 cm under the belly and 40 cm all around the cod-end.

Nine daylight hauls were carried out (Table IV) using the standard bottom cod-end (70 mm). For the first two hauls the net was fished with the cover unlaced at points A and B (Fig. 4). This gave the total numbers of *Nephrops* escaping through the belly of the net and the bottom cod-end. In hauls 3 and 4 only A was laced up; in haul 5 only B and in hauls 6 to 9 both A and B.

Large numbers of *Nephrops* were escaping from the covered areas of the net during trawling (Table IV). The length distributions of *Nephrops* retained by the 70 mm cod-end, the back cover and all three covers are shown in Figure 6. It might have been assumed that larger numbers of the smaller *Nephrops* (<25 mm CL) would escape from the net, but they did not. Many small *Nephrops* (20.3% by number) were retained in the 70 mm cod-end (Fig. 6a) and marketable sized *Nephrops* >25 mm CL, (31.5% by number) succeeded in escaping from the 70 mm cod-end into the cod-end cover (Fig. 6b). Figure 6 c shows the length frequency distribution of *Nephrops* escaping into the unlaced cover during two hauls (Table IV, hauls 1 and 2). It can be seen that a high proportion (59.5% by number) were greater than 25 mm CL. If these *Nephrops* had been caught, they would have increased the marketable catch of these two hauls by 46.8% by number.

It appears from Table IV that there were differences in the catches of *Nephrops* within the cover sections depending on how many points were fastened. The dye experiments did not show any measurable differences in the water flow through and between the net and cover, but the laced up cover may have had a slight blinding effect on the belly meshes. There was a tendency for the percentage of *Nephrops* escaping overall to decline as the cover was laced up. The data in Table IV however show that many *Nephrops* (undersize and marketable size) escape through the belly of the net before reaching the cod-end.

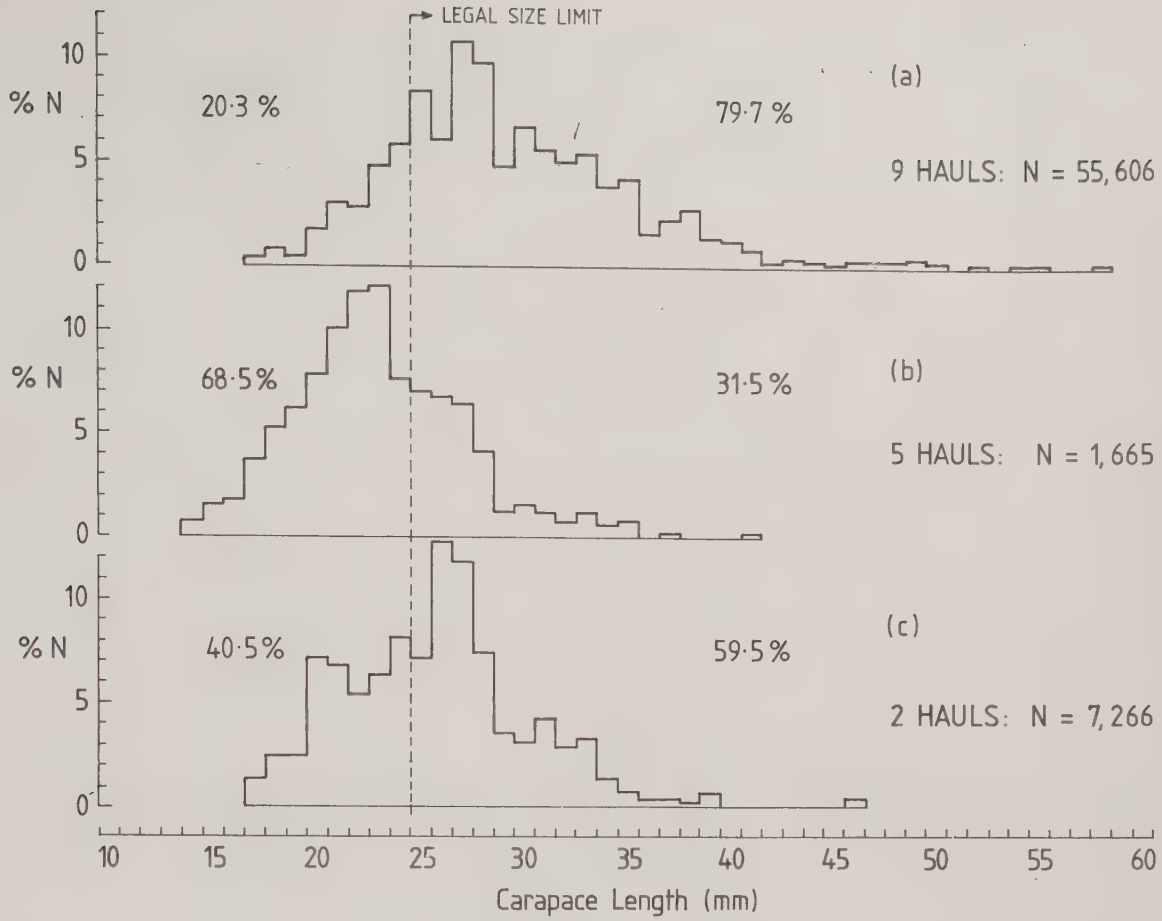

Figure 6. The length frequency distribution of *Nephrops* catches in (a) the 70 mm bottom cod-end with the cover attached (2–3 hours duration, depth 56–110m), (b) the back cod-end cover and (c) the complete unlaced cover.

Figure 7 shows a *Nephrops* size selection curve for the 70 mm cod-end alone (*ie* restricted to the catches in the cod-end and the cod-end cover, excluding the belly cover data). This gives a 50% capture length of 28.2 mm (CL) and a selection range between quartiles of 13.5 mm. The 50% retention CL divided by the mesh size gives a selection factor of 0.39.

Measurements and catches with the 80 mm cod-end

The results from hauls 1, 2 and 3 in Table V show as before that many *Nephrops* were escaping through the belly panel meshes before reaching the cod-end. In hauls 4 and 5 (Table V) the small mesh belly cover was removed, leaving only the bottom cod-end covered. The results show that the loss of *Nephrops* from within the 80 mm cod-end is high (up to 52.5% in haul 5).

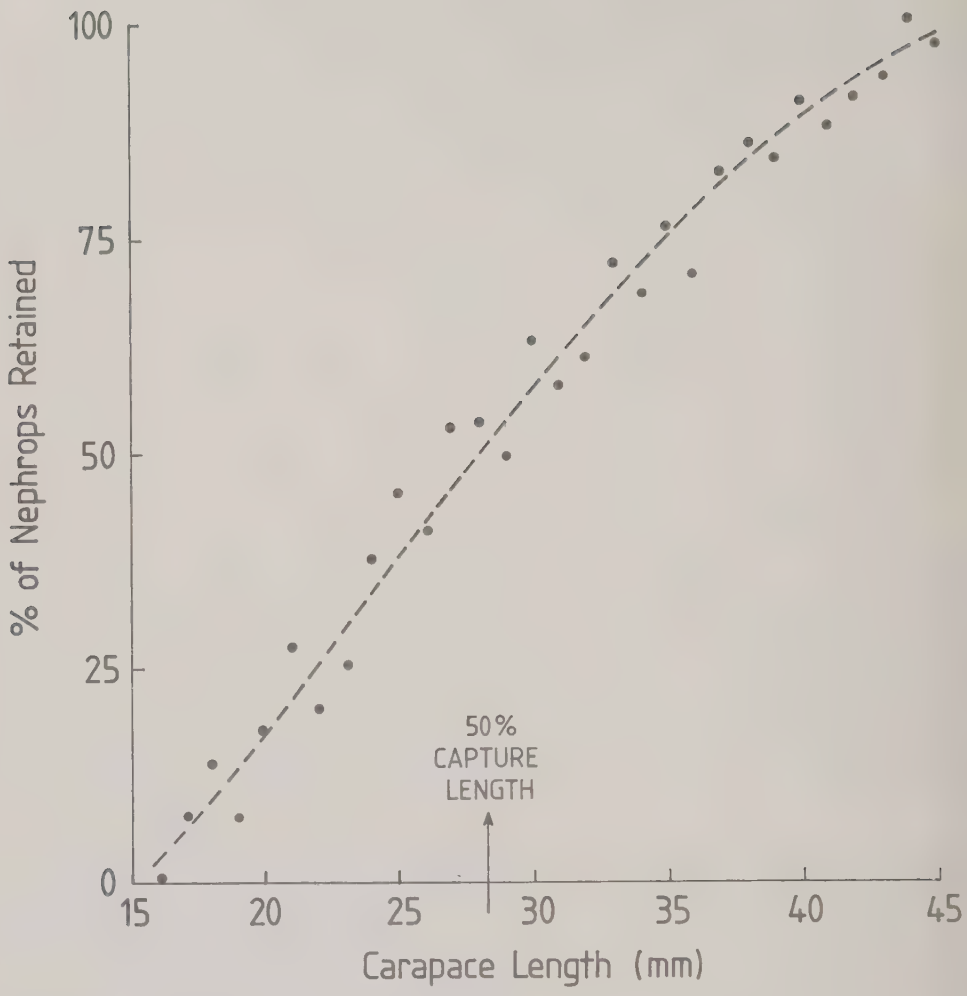

Figure 7. **Selection curve for the 70 mm bottom cod-end of a modified two level Boris 520 trawl.**

Table V ***Nephrops*** **catches using the 80 mm cod-end. Data from five daytime hauls (depth range 70—110 m, duration 2—2.5 hours)**

Haul	% retained in bottom cod-end	% retained in cover divisions			% total loss into covers from covered net	Cod-end + all covers Total catch in Numbers (N)
		Front	Middle	Back		
1	56.1	5.5	3.2	35.2	43.9	18,050
2	49.5	5.6	3.4	41.5	50.5	15,897
3	63.3	3.3	3.1	30.3	36.7	31.329
4	71.7	-	-	28.3	28.3	672
5	47.5	-	-	52.5	52.5	11,959
average	57.6				42.4	total 77,907

In hauls 1 to 3 (Table V) an average of 4.8% of the *Nephrops* escaped into the front cover, 3.2% into the middle and 35.6% into the back. For these three hauls, this gave an average loss of *Nephrops* from the net of 43.7% by number. If hauls 4 and 5 (Table V) are included the average overall total loss of *Nephrops* was 42.4% by number, of which the proportions below and above 25 mm CL were 52.3% and 47.7% respectively.

The length frequency distribution of cod-end and cod-end (back) cover catches is shown in Figure 8. It can be seen that 28.2% in the cod-end and 43.1% in the cover were below 25 mm CL. A selection curve for the 80 mm mesh cod-end (Fig. 9) shows a 50% capture length of 26.4 mm, giving a selection factor of 0.32 and a selection range between quartiles of 24.6 mm.

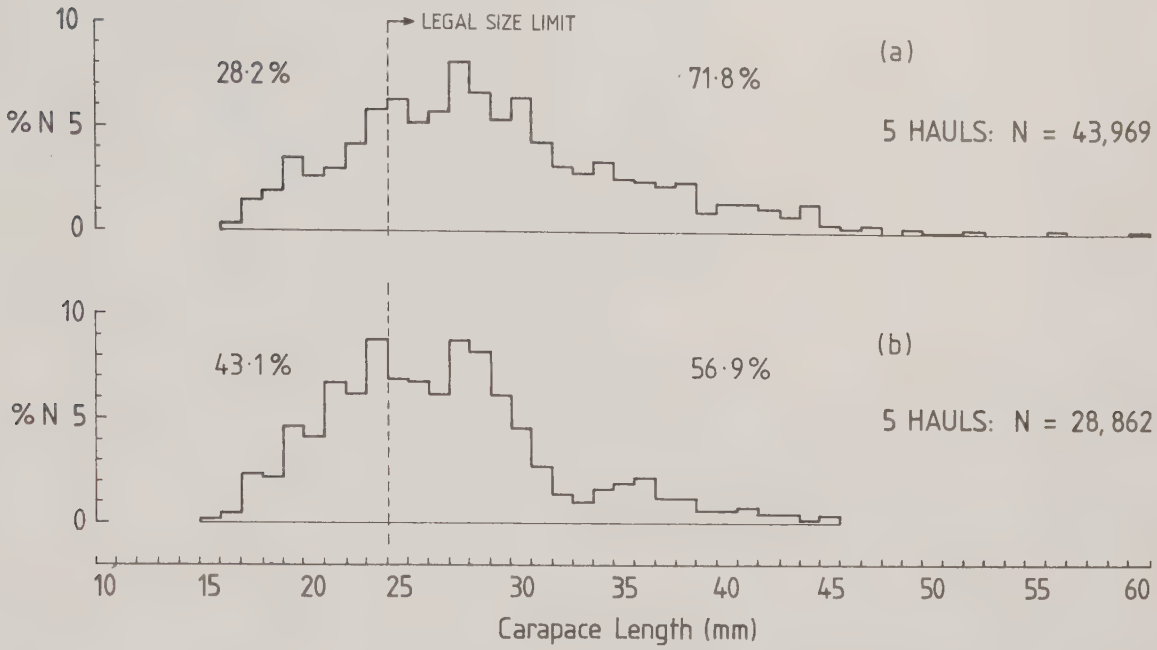

Figure 8. **The length frequency distribution of *Nephrops* catches in (a) the 80 mm bottom cod-end with the cover attached and (b) the back cover.**

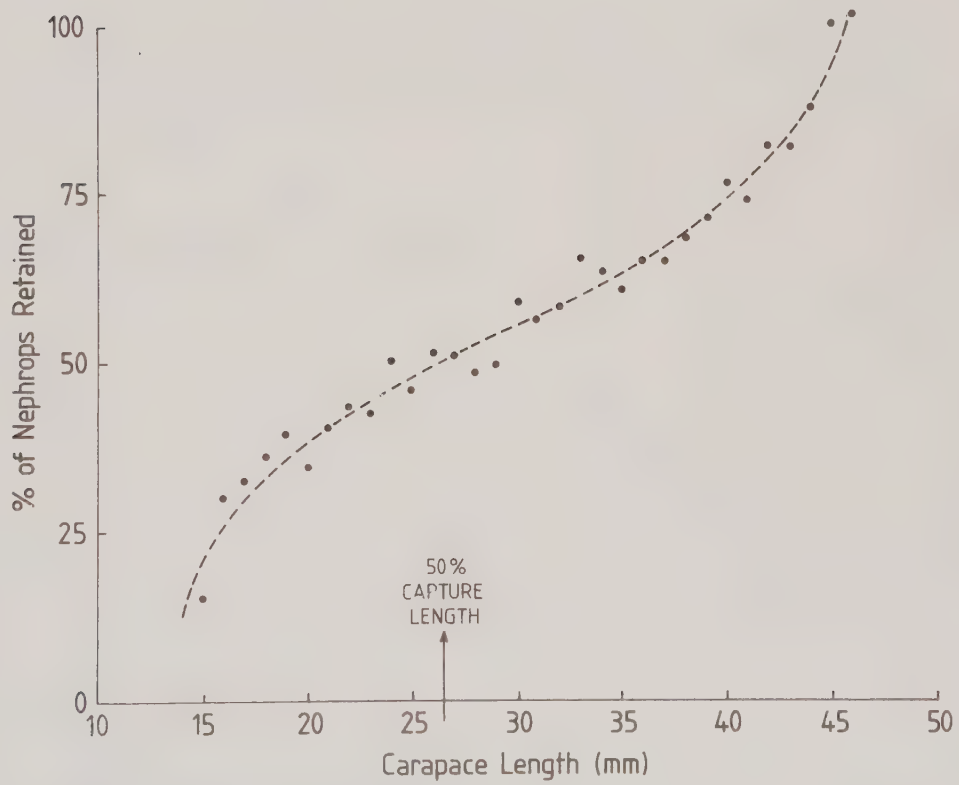

Figure 9. **Selection curve for the 80 mm bottom cod-end of a modified two-level Boris 520 trawl.**

Measurements and catches with the 90 mm cod-end

From Table VI it can be seen that between a third and a half of the *Nephrops* escaped into the covered areas during trawling using the 90 mm mesh cod-end. As before small proportions of *Nephrops* escaped through the 70 mm belly panels into the front and middle covers before reaching the cod-end. Figure 10 shows the length frequency distribution of *Nephrops* retained by the 90 mm cod-end and cover and again shows that many *Nephrops* below 25 mm CL did not escape even through this large mesh size. Of the total catch from the five hauls 19.1% of *Nephrops* in the cod-end and 34.5% in the back cover were under-sized. In haul 5 (Table VI) the two forward compartments of the small mesh cover had again been removed, leaving only the bottom cod-end covered. *Nephrops* recovered from all three divisions of the small mesh cover totalled 22,942, of which 44.8% were less than 25 mm CL and the remainder were above that size.

Table VI *Nephrops* **catches using the large mesh (90 mm) cod-end. Data from five daytime hauls (depth range 70–140 mm; duration 2–2.5 hours)**

Haul	% retained in bottom cod-end	% retained in cover divisions			% total loss into covers from covered net	Cod-end + all covers Total catch in Numbers (N)
		Front	Middle	Back		
1	50.8	11.4	6.7	31.1	49.2	16,250
2	61.9	0.1	2.3	35.7	38.1	1,853
3	66.3	0	6.6	27.1	33.7	8,670
4	61.9	19.6		18.5	38.1	17,946
5	59.9	-	-	40.1	40.1	11,178
average	60.2				39.8	total 55,897

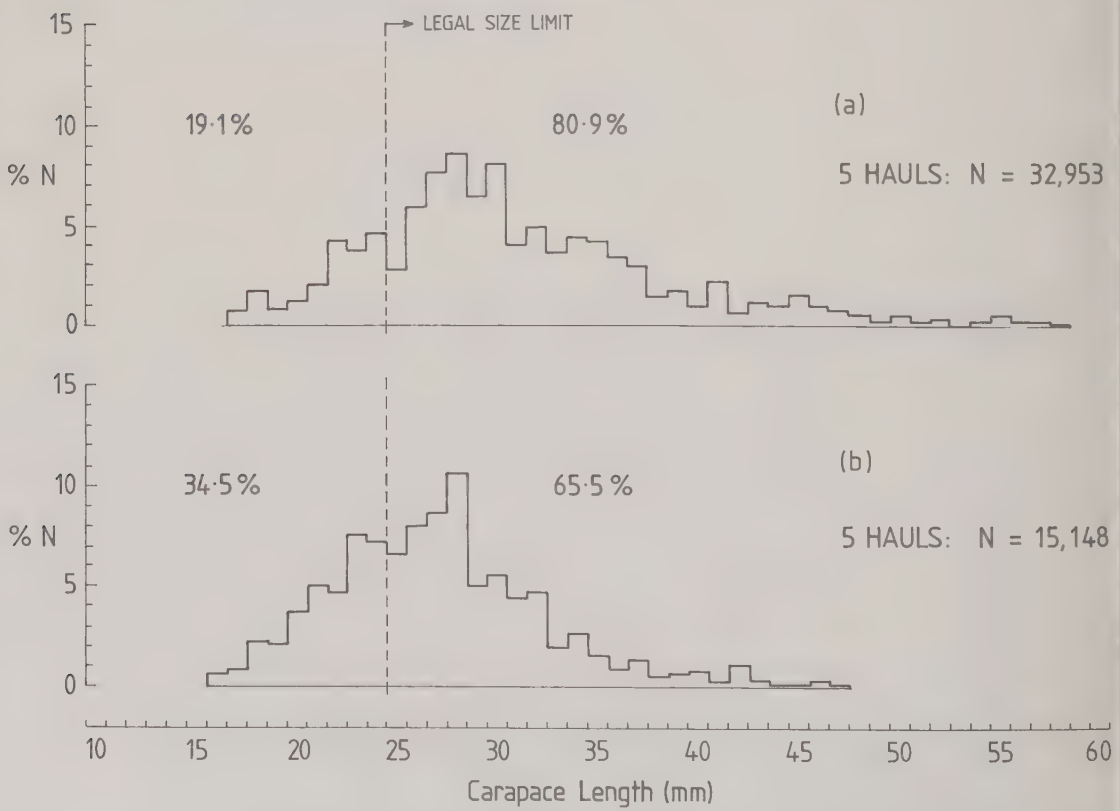

Figure 10. The length frequency distribution of *Nephrops* **catches in (a) the 90 mm bottom cod-end with the cover attached and (b) the back cover.**

Figure 11 shows a selection curve for the 90 mm mesh cod-end, giving a 50% capture length of 26.7 mm CL, a selection factor of 0.29 and a selection range of 18.6 mm.

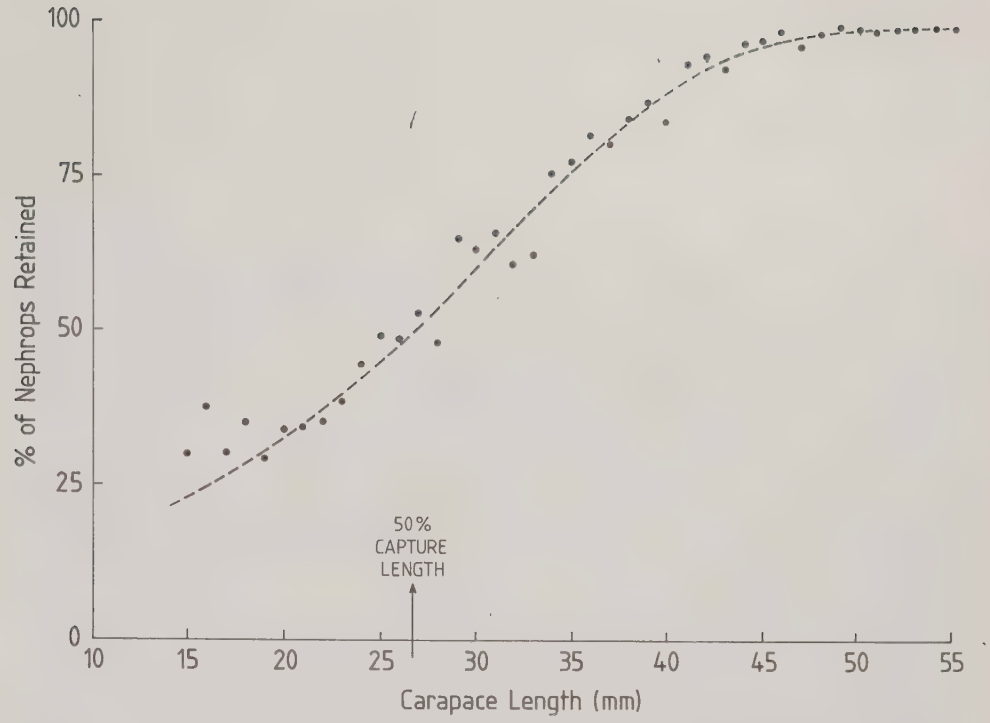

Figure 11. Selection curve for the 90 mm bottom cod-end of a modified two-level Boris 520 trawl.

Selection by belly panel

Since no changes were made to the 70 mm mesh belly panels of the Boris 520 net, the numbers and size composition of *Nephrops* escaping from the front and middle areas of the belly panels in all hauls, where the three compartments were intact, were pooled to give an indication of selectivity of the belly of the net. The data are shown in Figure 12 and reveal that roughly equal numbers of under-sized and marketable sized *Nephrops* escaped through the 70 mm mesh belly panels before reaching the cod-end. It is notable that no large animals over 45 mm CL found a way out through the 70 mm belly panels.

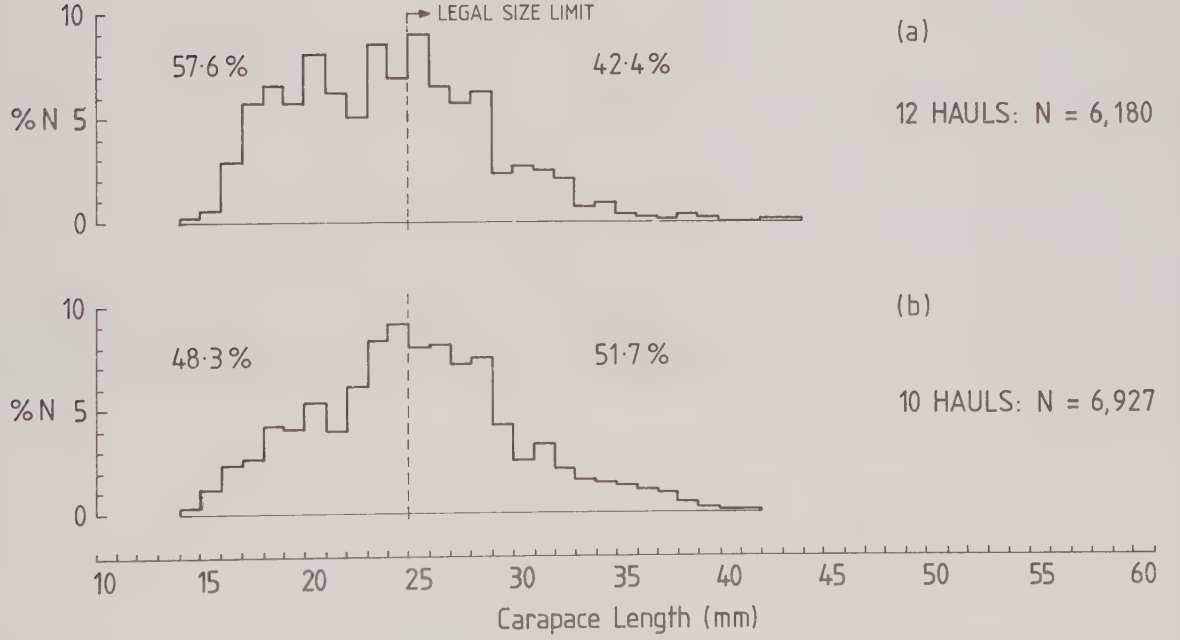

Figure 12. The length frequency of the *Nephrops* catches in (a) the front area and (b) the middle area of the small mesh cover.

Discussion

These experiments have revealed several advantages in combining direct observations of the behaviour of the *Nephrops* with measurements of the catching performance and selectivity of the nets. They showed the benefit of studying *Nephrops* behaviour *in situ* in order to gain a better understanding of the trawling process and to aid interpretation of the catches. Furthermore, divers could check that the trawling gear was fishing correctly before beginning the comparative fishing. This is especially important when using modified nets and/or small mesh covers to show whether the rigging or tailoring alterations would have affected the catches or prevented escapes.

Direct Observations

During 12 hours of searching only 126 *Nephrops* were seen out of their burrows on the mud surface in the area between the otterboards and the wing-ends of the net and most of these were over-run by the sweeps and bridles. Furthermore, in other experiments during bottom trawling by FRV "Explorer" in April 1982 on a muddy sea bed (depth 70–75 m towing speed 1.5 m s^{-1}), remote television camera observations of the individual reactions of 221 *Nephrops* to a 20 mm diameter steel trawl bridle were recorded using red light. It was observed that 193 of the *Nephrops* were over-run or hit, then over-run by the bridle and avoided capture, whilst the others reacted by moving inwards a short distance (1–2 m) into the path of the gear (Plate VII). It seems likely that those *Nephrops* which did move inwards were over-run further along the sweep out of camera range. It appears from these observations that no herding of *Nephrops* by bridles takes place during trawling and suggests that sweeps and bridles have little effect on the *Nephrops* catch. This is in contrast to observations of the herding effect on fish by the sand cloud disturbed by the otterboards (Bagenal, 1958; Main and Sangster, 1981a, b).

Plate VII. A *Nephrops* **moving inwards a short distance away from the approaching trawl bridle.**

Our observations showed that with normal sea-bed contact of the bosom ground gear all *Nephrops* out of their burrows in line with the track of the trawl mouth responded by swimming up and over the fishing line into the net. Those *Nephrops* in their burrow entrances escaped by withdrawing

deeper into their burrows. A few *Nephrops* attempted to outswim the trawl by repeated tail "flick" swimming movements (Plate VIII). Such bursts of swimming (at a towing speed of 1.3 m s^{-1}) were very brief, suggesting perhaps that *Nephrops* were quickly exhausted at this speed. Little is known of the endurance of *Nephrops* stimulated to swim by an approaching trawl. More measurements are needed.

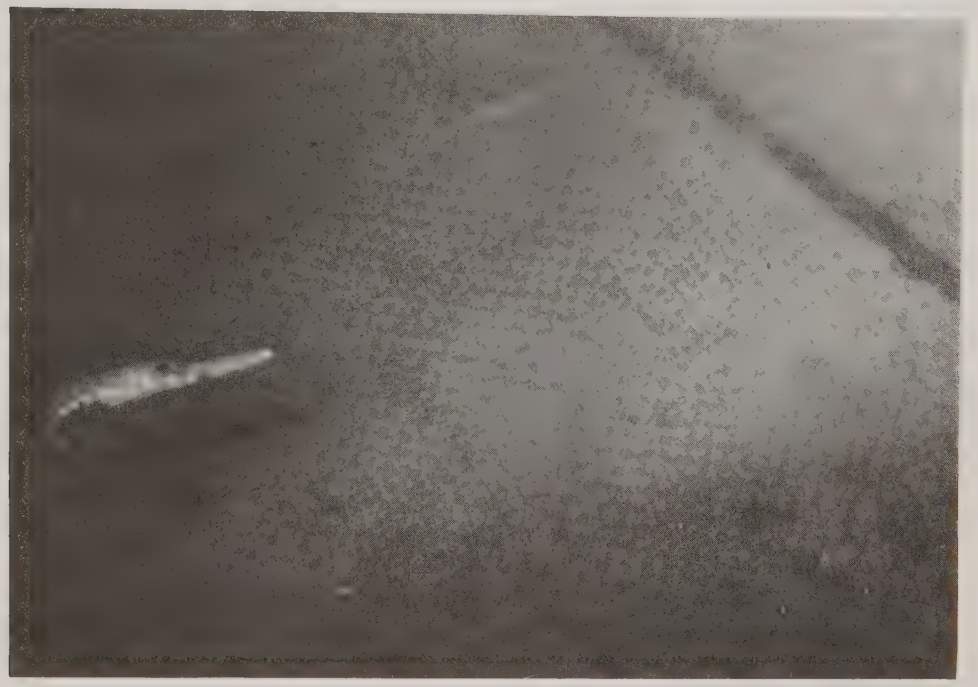

Plate VIII. A *Nephrops* **attempting to outswim the approaching bridle by using several continuous tail flick movements.**

Trawl Cover Experiments

Briggs and Watson (1980) carried out comparative fishing experiments using two vessels towing side by side and without small mesh covers on the nets. They compared the *Nephrops* catches of two gears, a 520 Dual Purpose trawl and a standard Irish prawn trawl, both fitted with 40 mm cod-ends. The standard net had a mesh size of 40 mm throughout; the 520 net had meshes of 76 mm in the lower wings, quarters and forward belly panels, and 40 mm meshes in the after batings panel just ahead of the cod-end. Although they found no significant difference between the mean carapace length of *Nephrops* taken by these nets, there was a tendency for the standard net to catch a higher proportion of small *Nephrops.* The authors concluded that this was due to the escape of small *Nephrops* through the larger meshes in the wings and the belly of the dual purpose trawl. The size of *Nephrops* caught ranged from 13 to 42 mm CL. However, without using small mesh covers or direct observation to find the actual quantities of *Nephrops* passing through the meshes in the different areas of these two nets, it is difficult to draw conclusions concerning the maximum or minimum escape areas of these trawls by comparing the compositions of the two cod-end catches. Nevertheless their prediction of the 76 mm mesh belly panel of the dual purpose net as being a possible escape area for "prawns" is confirmed by our covered net experiments and direct observations, and also by the results of Cole and Simpson (1965). Cole and Simpson used six covers of equal area (area and mesh size unspecified) on a 70 mm uniform "prawn" trawl fished in the Irish Sea. It was found that large numbers of small *Nephrops* were caught in three covers in the areas of the bunt (or quarters) and belly and under the cod-end. None were found in the wing-end covers, but it was suspected that the wing-ends were not on the ground. In their seven trawl hauls an average of 1,252 *Nephrops* were retained in the

cod-end, or just a quarter of all the *Nephrops* that entered the net; the rest were taken in the small mesh covers. The size of *Nephrops* recovered from their net ranged from 10 to 54 mm CL (mean 24 mm CL). Hillis and Earley (1982) used a uniform mesh (52 mm), standard Irish "prawn" trawl and sampled *Nephrops* escaping through the wings, quarters and belly areas by attaching fifty-two small mesh (15 mm) pockets to these points in the trawl. They found many *Nephrops* escaping through the wings and quarters but few through the belly panels. 41.9% escaped through all covered areas of the trawl excluding the cod-end. They concluded that the area of maximum escape extended forward along the centre of the under-side of each wing of the trawl and the small mesh pockets on the body of the net aft of the wings caught very few. The size range of escaping *Nephrops* was 9—26 mm CL (mean 16 mm) in the wings, 9—28 mm CL (mean 19 mm) in the quarters and 9—25 mm (mean 18 mm) in the belly area. The largest size of *Nephrops* retained in the 58 mm cod-end was 35 mm CL. These results of Hillis and Earley (1982) do, to a certain extent, contrast with our own findings. In our covered net experiments (Table IV) a large proportion of *Nephrops* escaped through the belly panel into the front and middle sections of the cover (this result agrees with the findings of Cole and Simpson, 1965). Analysis of the pooled data of all the *Nephrops* recovered from these two areas when compared with the total caught by the net and cover showed that 10.8% (size range 15—43 mm CL, mean 25 mm CL) passed into the front and 6.4% (size range 14—41 mm CL, mean 26 mm) into the middle section of the cover. This gives a figure of 17.2% of *Nephrops* escaping through the belly of the net before the cod-end region. The largest *Nephrops* retained in the 70 mm mesh cod-end was 59 mm CL. It must be noted, however, that small mesh covers were not attached to the wing areas during our experiments. These experiments were planned to investigate and establish the findings of our previous direct observations of *Nephrops* escaping through the belly panels and the cod-end. Although our more recent unpublished direct observations have shown *Nephrops* (estimated at marketable size) rising over the ground-line, striking and being caught in the wing meshes (Plate IX), none have been seen escaping in this area. However, were smaller sized *Nephrops* escaping through the wing areas of our 70 mm net? In the Irish *Nephrops* experiment (Hillis and Earley, 1982), the size of animals caught in the wing small mesh pockets of the 58 mm Irish prawn trawl ranged from 9 to 26 mm CL. The *Nephrops* in this Irish fishery are smaller (size range 9—35 mm CL) than those caught during our experiments (size range 14—59 mm CL). It was further concluded by Hillis and Earley (1982) that the size of escaping *Nephrops* decreases progressively forward from the cod-end to the wings. It seems likely, therefore, that more of the smaller sized *Nephrops* could have escaped from the front part of the trawl and probably did so during our experiments, but were never seen, and because of the absence of covers over the wing area these small *Nephrops* were never caught.

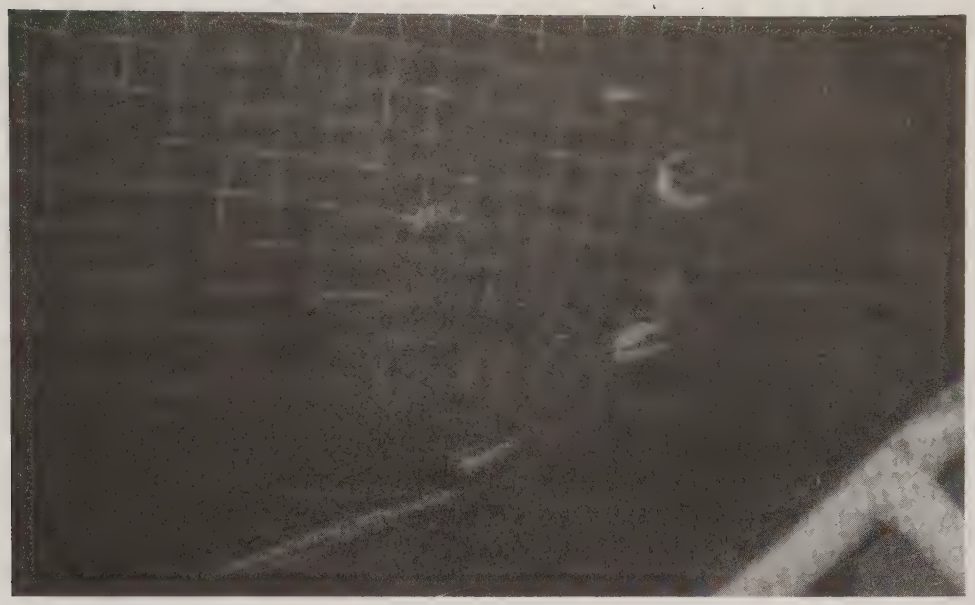

Plate IX. *Nephrops* **meshed in the lower port side wing of the two-level trawl.**

Summary

Direct observations of the reactions of *Nephrops norvegicus* (L.) to two types of fishing gears were made in daylight using both divers and a remotely controlled television camera on an underwater vehicle. One net was a standard commercial gear, the other a modified dual purpose fish/prawn trawl tailored with a second fishing line on a horizontal separator panel which divided the net into two compartments terminating in separate cod-ends. All the *Nephrops* seen out of their burrows on the sea-bed in line with the track of the trawl mouth passed back into the net. Those in the entrance of a burrow escaped capture by withdrawing into that burrow as the gear passed over. Most of the *Nephrops* outside the track of the mouth of the net (*ie* in the area between the otterboards and the wing-ends) avoided capture by swimming or skipping up a few centimetres allowing the sweeps and bottom bridles to pass under them. A few *Nephrops* used repeated tail "flick" swimming movements in an attempt to outswim the approaching trawl, but at a towing speed of 1.3 m s^{-1}, their short bursts of swimming endurance suggested that these animals are quickly exhausted and they then allow the fishing line to overtake them.

Covered net experiments with the two-level trawl, designed in a way to retain all *Nephrops* passing down through the lower half of the net, demonstrated that many *Nephrops* escaped through the 70 mm mesh panels in this area. The cover was divided in such a way as to preserve the identity of animals escaping from three areas on the underside of the net. Both small and marketable sized *Nephrops* were caught in all areas of the cover. Three different cod-ends were compared by substituting the standard 70 mm with 80 mm and 90 mm mesh sizes. No animal over 45 mm (carapace length) found a way through the standard 70 mm mesh.

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